20–7 Solenoids and Electromagnets

A long coil of wire consisting of many loops (or turns) of wire is called a **solenoid**. The magnetic field within a solenoid can be fairly large because it is the sum of the fields due to the current in each loop (Fig. 20–26). A solenoid acts like a magnet; one end can be considered the north pole and the other the south pole, depending on the direction of the current in the loops (use the right-hand rule). Since the magnetic field lines leave the north pole of a magnet, the north pole of the solenoid in Fig. 20–26 is on the right. As we will see in the next Section, the magnetic field inside a tightly wrapped solenoid with N turns of wire in a length l, each carrying current I, is

$$B = \mu_0 I N / l. \quad \textbf{(20–8)}$$

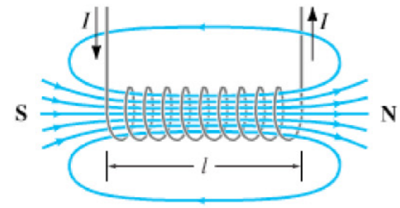

FIGURE 20–26 Magnetic field of a solenoid. The north pole of this solenoid, thought of as a magnet, is on the right, and the south pole is on the left.

If a piece of iron is placed inside a solenoid, the magnetic field is increased greatly because the iron becomes a magnet. The resulting magnetic field is the sum of that due to the current and that due to the iron, and can be hundreds or thousands of times that due to the current alone (see Section 20–12). Such an iron-core solenoid is an **electromagnet**.

PHYSICS APPLIED
Electromagnets and solenoids

Electromagnets have many practical applications, from use in motors and generators to producing large magnetic fields for research. Sometimes an iron core is not present—the magnetic field comes only from the current in the wire coils. For some applications, the current-carrying wires are made of superconducting material kept below the transition temperature (Section 18–9). Very high fields can be produced with superconducting wire without using an iron core. No electric power is needed to maintain large current in the superconducting coils, which means large savings of energy; nor must huge amounts of heat be dissipated.

Another useful device consists of a solenoid into which a rod of iron is partially inserted. This combination is also referred to as a solenoid. One simple use is as a doorbell (Fig. 20–27). When the circuit is closed by pushing the button, the coil effectively becomes a magnet and exerts a force on the iron rod. The rod is pulled into the coil and strikes the bell. A large solenoid is used in the starters of cars; when you engage the starter, you are closing a circuit that not only turns the starter motor, but activates a solenoid that first moves the starter into direct contact with the gears on the engine's flywheel. Solenoids are used as switches in many devices. They have the advantage of moving mechanical parts quickly and accurately.

PHYSICS APPLIED
Doorbell, car starter

Modern circuit breakers that protect houses and buildings from overload and fire contain not only a "thermal" part (bimetallic strip as described in Section 18–6, Fig. 18–19) but also a magnetic sensor. If the current is above a certain level, the magnetic field it produces pulls an iron plate that breaks the same contact points as in Fig. 18–19b and c. In more sophisticated circuit breakers, including ground fault circuit interrupters (GFCIs—discussed in Section 21–8), a solenoid is used. The iron rod of Fig. 20–27, instead of striking a bell, strikes one side of a pair of points, opening them and opening the circuit. Magnetic circuit breakers react quickly (<10 msec), and for buildings are designed to react to the high currents of shorts (but not shut off for the start-up surges of motors).

PHYSICS APPLIED
Magnetic circuit breakers

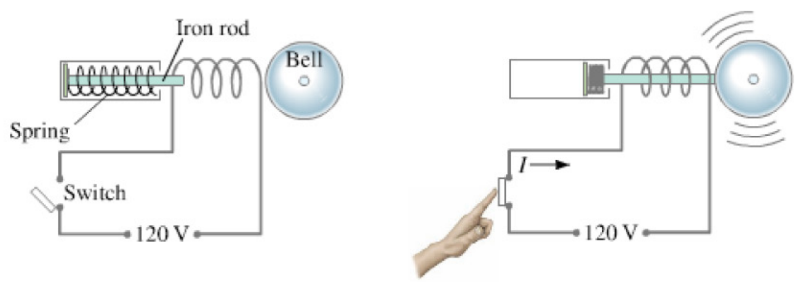

FIGURE 20–27 Solenoid used as a doorbell.